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MICROWAVE DRYING OF COTTONSEED

Energy Utilization and Its Effect on Seed-Mass Temperature and Seed Germination

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MICROWAVE DRYING OF COTTONSEED
Energy Utilization and Its Effect on Seed-Mass Temperature and Seed Germination

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SUMMARY

The moisture content of cottonseed was reduced rapidly using microwave energy. The temperature of the seed mass increased as the moisture level of the seed decreased. Utilization of the microwave energy for removing seed moisture ranged from 17.3% to 31.4%. An increase in seed germination was recorded for the lower energy exposure levels; however, extended exposure times of the seed to the microwave energy produced marked decreases in seed germination.

INTRODUCTION

Drying of seed cotton is essential to the maintenance of the inherent quality of the cotton during ginning; drying results in better preparation and smoothness of ginning. The efficiency of the cleaning operation is also increased by the reduction of lint and seed moisture.

Seed cotton drying became an integral part of the ginning system in the early 1930's, when the vertical drier was shown to be a practical method for drying seed cotton (*6*).[4]

The increasing popularity of the vertical seed cotton drier resulted in numerous modifications, which eventually led to the development of the multipath drying system (*5*). This system consists of a 24-shelf tower drier with the capability of path selection. The paths were designed to utilize different numbers of shelves, thus exposing the seed cotton to more or less time in the hot airstream circulating through the drier.

An economic study by Wilmot and Watson in 1966 (*12*) indicated that the drying process accounted for an average of 25% to 30% of the total electric energy consumption and cost for operating high-capacity gins. Energy consumption and cost for drying were higher than for any other single function. The average energy consumption was 14.16 kilowatt-hours per bale ginned at an equivalent average cost of 35.73 cents. In some cases, the energy cost for drying was approximately double the second most costly function. It is conceivable that microwave energy, with its increased rate of moisture removal, may eventually be economically feasible for drying seed cotton and cotton products.

Mechanized harvesting of cotton has increased dramatically during the last decade, greatly reducing the length of the harvest season and increasing the rate of flow of seed cotton to the gin yard. During the ginning season, gin yards are often crowded with trailers of seed cotton waiting to be ginned.

Efforts to eliminate such crowding include separate unloading and storage facilities at numerous gin plants and, most effective, the development of the high-capacity gin stand. As the technology of harvesting and processing continues to improve, it is obvious that faster and cheaper methods of drying seed cotton will be required.

Microwave energy is now used in the manufacture of plywood and laminated furniture, freeze drying and dehydrating of food products, and the drying of paper and textiles during proc-

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[4] Italic numbers in parentheses refer to items in "Literature Cited," p. 13.

essing. Because of its successful application in such drying processes, it appeared desirable to investigate its applicability to drying of seed cotton.

OBJECTIVES

Cottonseed was selected as the constituent to be tested initially because it constitutes two-thirds of the weight of seed cotton and contains approximately 70% of the total moisture. Although lint moisture is more critical in ginning than seed moisture content, microwave drying of seed cotton would not be practical if it has a detrimental effect on cottonseed (*11*).

The specific objectives of this research were

1. To develop equations that will predict the drying of cottonseed with respect to time of exposure for the various seed moisture levels and energy input rates.
2. To establish equations that will predict seed-mass temperature with respect to time of exposure for various seed moisture levels and energy input rates.
3. To develop data relative to the utilization of microwave energy for drying cottonseed.
4. To establish seed germination equations with respect to time of exposure for the various seed moisture levels and energy input rates.

REVIEW OF LITERATURE

General

The drying efficiency of microwave energy appears to stem from the fact that it is absorbed more readily by water throughout the volume of the product than by the structural component of the product itself. The microwave energy is converted into heat, which raises the vapor pressure of the water and accelerates the drying process.

Microwave Drying

Description of microwaves

Microwave energy is electromagnetic energy and is classified according to frequency. The microwave frequency band of the electromagnetic spectrum lies between 10^6 and 10^{11} hertz.

Wavelength is related to frequency by the equation $Y = c/f$, where Y = wavelength (meters), c = speed of light (3×10^8 meters/second), and f = frequency (hertz).

Applications for industrial, scientific, and medical purposes have been assigned microwave frequencies of 915 and 2,450 megahertz. These frequencies are equivalent to wavelengths of 0.328 and 0.122 meters, respectively.

Principles of microwave drying

In microwave heating, energy is transferred by waves to the material to be heated (*3*). Generally, these materials are nonconductors of electricity (dielectrics). Most dielectrics contain varying amounts of water and absorb energy from the electromagnetic field in various quantities. The absorbed energy causes movement of molecules which continues until the kinetic thermal energy creates areas of high vapor pressure.

In the microwave frequency range, the loss factor (absorption characteristic) of water is many times greater than the loss factor for most textile materials. As microwave energy is applied, the high loss factor of water causes a thermal gradient to form at internal locations having high moisture concentrations. These conditions establish vapor pressure gradients inside the material which tend to move moisture outward to areas of lower vapor pressure.

Effects of microwave drying

During the past 20 years, research workers have investigated numerous applications of microwave energy to agricultural products.

Hamid and Boulanger (*7*) investigated the control of moisture and insect infestations in grains, using two stages of drying. Moisture contents of the grain were reduced from 16.5% to 13.3% by the application of 1.2 kilowatts at a frequency of 2,450 megahertz. Boulanger, Boerner, and Hamid (*2*) also investigated the effects of airflow rates. Results of their tests revealed that the moisture content of wheat was reduced from 20% to 15% by application of microwave energy at 2,450 megahertz for 15 minutes at an airflow rate of 500 cubic feet per minute.

Fanslow and Saul (*4*) also investigated drying field corn with microwave power and unheated air. The investigation included three samples sizes (weights), three airflow rates through the microwave cavity, and three processing times. This investigation indicated the market value of the product was reduced due to swelling of the kernels after 3 minutes' exposure time. Airflow rates did not have a significant effect on drying rates. Limited data indicated that drying rates of rewet corn did not differ significantly from freshly harvested corn.

Nelson, Nutile, and Stetson (*10*) report that brief exposures of radio-frequency energy substantially increased the germination of okra, field peas, and garden beans. Seeds with high initial germination were not affected by the treatment. Overexposure to the radio-frequency field delayed germination and increased the percentage of dead seeds.

Jolly and Tate (*8*) report significant increases in germination of Douglas-fir seed subjected to specified levels of microwave energy. The most favorable combination of microwave energy level and exposure time increased seedling yield 25%.

EXPERIMENTAL PROCEDURES

Experimental Design

The design for this investigation was a randomized complete block arranged as a 3 by 3 by 5 factorial and replicated 3 times. The factors investigated were (1) cottonseed moisture levels, (2) energy input rates, and (3) times of exposure of the seed to microwave energy. Seed sample size and airflow rate through the microwave cavity were held constant.

The levels of the selected factors were based on previous research (*4*, *8*) and the overall objectives of the investigation. To simulate field conditions, the target cottonseed moisture levels chosen were 10.0%, 16.0%, and 22.0%, dry basis.[5] Actual cottonseed moistures obtained were 10.4%, 16.4%, and 22.0%. Hereafter, these will be referred to as 10%, 16%, and 22%. Energy input rates of 200, 400, and 600 watts were selected. Exposure times were 2, 4, 6, 8, and 10 minutes.

The combinations of energy input rates, exposure times, and seed sample size established a desired minimum and maximum effective energy level. The minimum level was approximately 5 watt-seconds per seed and was designed to investigate the beneficial effects on seed quality, mainly enhancement of seed germination. The maximum level, approximately 50 watt-seconds per seed, was set in the upper range of moisture removal rate, and at a level that was expected to reduce seed viability.

Limited data were collected for extended exposure times of 13, 20, and 30 minutes for each of the replications. Data obtained from the extended exposure times were used only to extend the cottonseed drying curves. During these extended runs, some of the seed were burned, cracked, and damaged. The extended tests at the 400- and 600-watt energy levels were terminated at 20 and 13 minutes, respectively, because of bursting and burning of the seed.

Cottonseed Sample Material

Approximately 550 pounds of seed cotton ('Coker 201' variety) were selected for the investigation. The cotton was planted on May 1, 1971, and handpicked on November 12, 1971. In tests made after harvesting and before microwave drying, seed germination was 70%.

On November 16, 1971, the seed cotton was processed through a 20-saw gin in order to prevent unnecessary damage due to pneumatic conveying. As the seed cotton was ginned, three test lots—each consisting of 115 pounds of gin-run seed—were collected. The lots were placed in burlap bags and were arbitrarily assigned to block 1, 2, or 3 (replications). The seed was stored at 75° F and 60% RH (relative humidity) for 53 days.

On the 54th day, ovendry moisture determinations, made for each block, revealed an average moisture content of 10.4%. Twenty 700-gram experimental units of seed from each block were weighed, placed in moisture-proof cans, sealed, and labeled.

An additional 35-pound sample of seed from each block was placed in an open-top, wire-bottom tray (fig. 1), in an environmentally controlled chamber to bring it to the 16% moisture level. The chamber was set at 78° F and 84% RH as described by Karon (*9*). The seed was thoroughly mixed each day to assure uniform

FIGURE 1.—Seed conditioning trays.

[5] All moisture contents are expressed as percent, dry basis.

moisture absorption throughout the mass. Because of malfunctioning of the chamber, 12 days were required to obtain the desired 16% nominal moisture level (16.4% ovendry moisture). Twenty experimental units of 700 grams each from each block were weighed, sealed, and labeled.

Since Bailey (*1*) indicated that high temperature and humidity levels caused a decrease in seed germination when high-moisture-content seed was stored, the seed for the 22% level was conditioned by blocks. Atmospheric conditions were controlled at 78° F and 92% RH.

Ovendry moisture determinations indicated the moisture content of the block 1 seed was 22.3% after 16 days. Twenty experimental units from this lot were weighed and processed as previously described.

Improvements were then made in the chamber air-circulating system to decrease the time required to bring the seed to 22% moisture. Seed from block 2 reached the 22% moisture level in only 8 days, and seed from block 3 measured 21.8% after 7 days.

The following precautions were taken during the storage of the seed samples:

1. "Canned" samples were selected at random and weighed daily in order to detect any change of weight due to moisture variation.

2. A control sample was selected at random from the canned seed samples of each moisture level for each of the three blocks (replications). These control samples were handled the same way as the 20 experimental units.

3. The experimental units of each replication were stored at room temperature in the microwave laboratory for at least 24 hours before the experimental microwave drying treatment, to help assure uniform temperature and moisture level throughout the seed mass within each can.

Test Equipment Setup

Figure 2 shows the microwave equipment and the instrumentation used in the investigation. The microwave generator, Genesys Systems Inc. model 4003, consisted of a 2,450-megahertz magnetron tube with a variable output up to 2.5 kilowatts. It was connected to the oven cavity by a short length of waveguide. The multimode cavity was aluminum with inside dimensions of 18 by 17 by 15 inches. An aluminum stirrer was used inside the cavity to assist in obtaining a uniform distribution of the microwave. Two power transducers were located in the waveguide between the magnetron and oven cavity to detect transmitted and reflected energy, so that absorbed energy could be determined.[6] A small blower with a capacity of 25 cubic feet per min-

[6] Transmitted energy is that energy emitted by the megnetron to the oven cavity, whereas the reflected energy is energy that failed to be absorbed by the seed sample and was reflected to the magnetron.

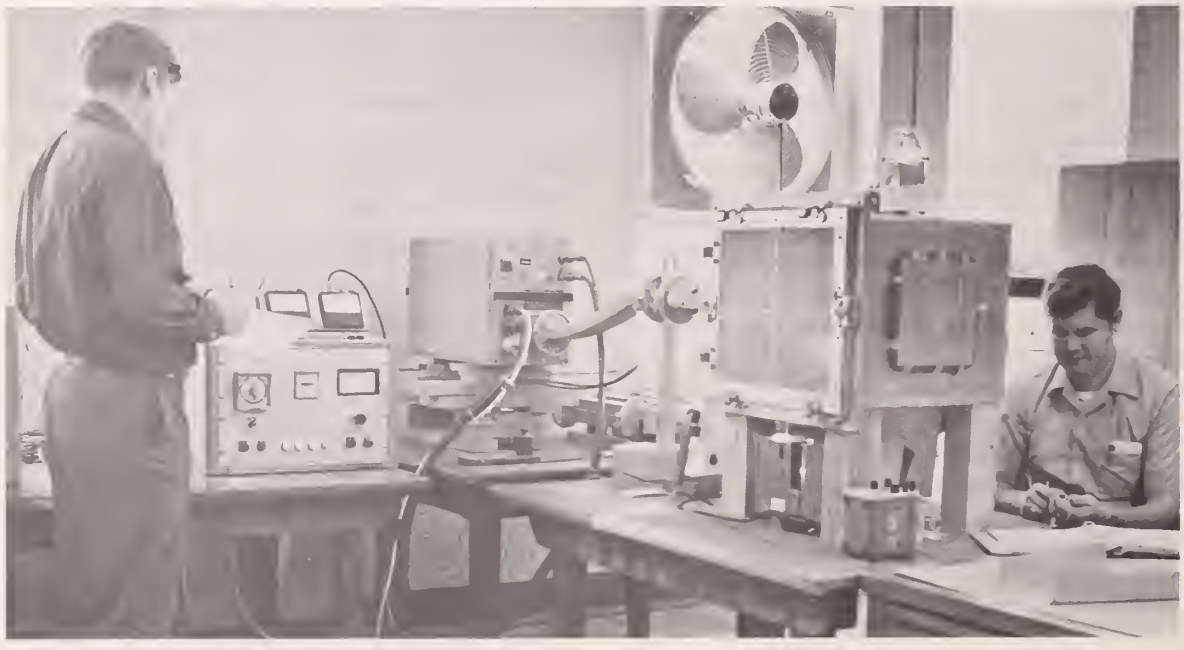

FIGURE 2.—Microwave equipment and instrumentation.

ute provided air circulation for removal of water vapor from the cavity.

A seed container (fig. 3) measuring 8 by 12 by 3 inches was made of Plexiglas to contain the seed sample during the drying cycle. It had an open top and a woven fine-mesh nylon bottom, and was supported by a Plexiglas platform connected to a Mettler model P1200 balance beneath the microwave oven. Figure 4 is a diagram of the microwave drying equipment and the seed container inside the microwave oven.

Instrumentation

The microwave generator was equipped with a variable output adjustment with a dial indicator that controlled the output range from 0 to 2,500 watts. It also contained an elapsed time indicator.

The balance monitored the weight of the seed continuously during the drying cycle. Sample weights were determined to the nearest 0.1 gram.

The initial and final seed temperatures were measured using a needle probe with a thermocouple on the end, connected to a pyrometer, Thermo-Electric Co., Inc., model 80200, which gave a direct readout of seed-mass temperature. The system was capable of measuring from 0° to 600° F with less than 10 seconds' lag.

Microwave Drying Procedures

The treatment combinations in each replication were processed according to the randomization plan. The metal can containing the specified seed sample was opened and the initial seed temperature recorded. The sample was transferred immediately to the Plexiglas sample container, placed in the microwave oven and weighed. The exposure time was set on the elapsed time indicator before the drying cycle was started. The energy input rate was adjusted immediately after the start of the drying cycle and was held constant throughout each test. The stirrer and the blower operated continuously during each drying test. The weight loss due to moisture removal was recorded at 1-minute intervals. At the conclusion of each drying cycle, the ambient temperature, relative humidity, and final seed-mass temperature were recorded. Each seed sample was placed in a paper bag and stored at 60° F and 50% RH. Germination tests were made after completion of the drying experiments.

Transmitted and reflected energy were measured for each test, using the power transducers mounted in the waveguide. From these data, the average rate at which the cottonseed absorbed the microwave energy was determined. The product of the rate of energy absorption (watts) and the exposure time (minutes) established the effective energy level (watt-minutes) for each treatment combination. To simplify calculations, the units of effective energy were converted to kilowatt-minutes.

RESULTS

Statistical Analysis

An analysis of variance was performed for each of the drying variables. Table 1 shows degrees of freedom, mean square, and level of

FIGURE 3.—Seed container and cottonseed sample.

1. Microwave generator
2. Transmitted and reflected power transducers
3. Microwave field stirrer
4. Water vapor outlet
5. Sample container
6. Sample holder
7. Weighing balance

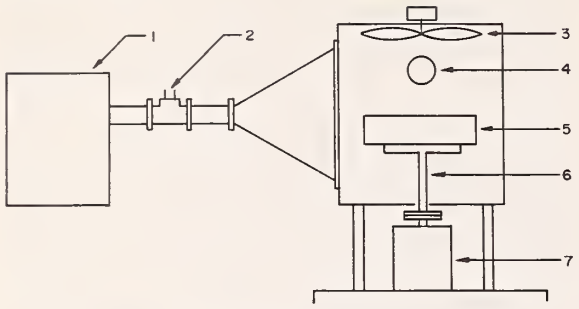

FIGURE 4.—Diagram of microwave oven.

significance for each source of variation. The results obtained for each drying variable are discussed in the following sections.

Moisture Removal

The weight loss due to moisture removal (table 2) was recorded at 1-minute intervals for each sample unit. These data, in conjunction with the initial weight of the seed sample and the initial moisture content of the seed, were used to determine seed moisture throughout each drying test.

A regression analysis of the drying data with respect to exposure time showed that a third-degree polynomial best described the data. The coefficients of determination for the various equations ranged from 0.979 to 0.997. Regression equations showing cottonseed moisture (percent dry basis) as a function of exposure time for the various combinations of seed moisture levels and energy input rates are shown in figures 5, 6, and 7.

The treatment means shown in table 2 indicate how the amount of moisture removed is dependent upon the level of each of the main factors. As the level of each factor increased, the amount of moisture removed increased. The significant interactions shown in table 1 indicate an interdependence of all the factors.

Reflected Energy

A summary of the treatment means of reflected energy is shown in table 3. A review of the means shows the reflected energy decreased

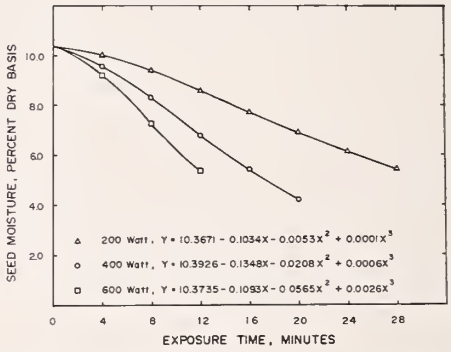

FIGURE 5.—Moisture content versus exposure time for seed having an initial moisture content of 10% (curves generated from prediction equations).

TABLE 1.—*Analysis of variance and significance levels for drying variables*

Source	*df*	Mean square			
		Moisture removed	Reflected energy	Seed-mass temperature	Seed germination
Blocks	2	13.19**	1,333.89**	486.76NS	0.01569555**
A (seed moisture level)	2	608.74**	30,915.00**	820.17*	.35400166**
B (energy input rate)	2	1,963.72**	92,967.22**	33,539.40**	1.59465055**
C (exposure time)	4	2,273.13**	3,599.35**	19,456.80**	.75678268**
AB interaction	4	58.32**	1,719.72**	386.83NS	.00385555NS
AC interaction	8	63.53**	471.02**	712.28**	.00953963**
BC interaction	8	208.01**	1,390.60**	1,009.99**	.06327740**
ABC interaction	16	6.09**	336.85**	425.33*	.00315289NS
Residual	88	1.01	66.62	208.69	.00304184
Total	134				

* Significant at the 5-percent level.
** Significant at the 1-percent level.
NS Not significant at the 5-percent level.

TABLE 2.—*Treatment means of moisture removed, in grams*

Initial % seed moisture (A)	Energy input rate, watts (B)	Exposure time in minutes (C)				
		2	4	6	8	10
10	200	1.86	3.56	5.07	6.97	9.23
10	400	2.23	5.27	9.03	13.03	18.00
10	600	3.00	7.27	13.53	20.87	26.30
16	200	2.26	4.57	7.77	10.67	14.90
16	400	2.77	7.93	14.07	21.87	27.30
16	600	3.89	11.40	22.73	32.37	41.03
22	200	2.50	4.67	8.90	10.70	15.73
22	400	3.43	8.27	15.50	23.47	32.70
22	600	4.30	13.10	24.60	36.60	46.53

as the seed moisture level increased, and increased as energy input rate increased. For seed moisture levels of 10%, 16%, and 22%, the energy reflected averaged 108.9, 72.2, and 57.4 watts, respectively. As the energy level increased from 200 to 600 watts, the reflected energy progressively increased from an average low of 35.9 to an average high of 126.2 watts. The average reflected energy also increased progressively from 68.9 to 97.8 watts as exposure time increased from 2 to 10 minutes.

Seed-Mass Temperature

The temperature of the seed mass was recorded just before and at the end of each drying test. The analysis of variance indicated all main factors and interactions AC, BC, and ABC were significant. Means appear in table 4.

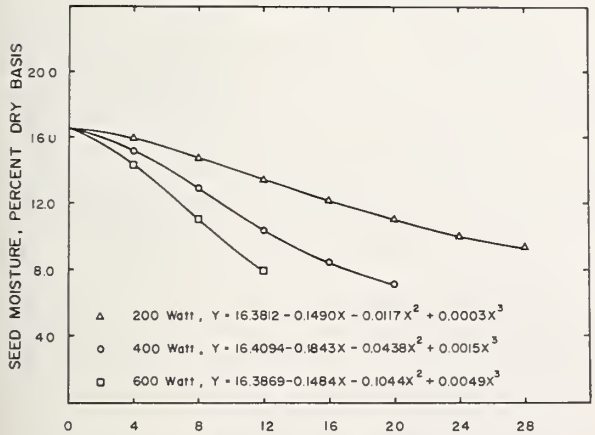

FIGURE 6.—Moisture content versus exposure time for seed having an initial moisture content of 16% (curves generated from prediction equations).

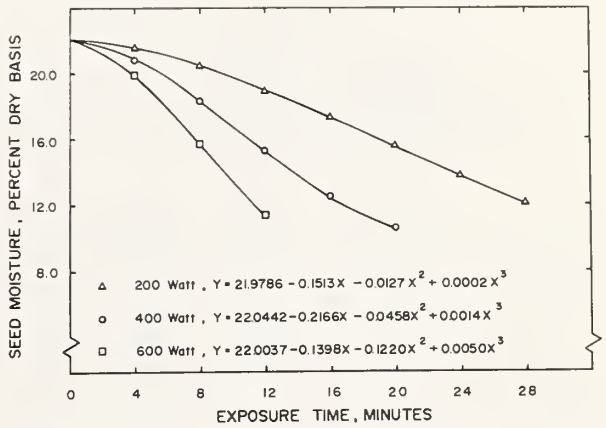

FIGURE 7.—Moisture content versus exposure time for seed having an initial moisture content of 22% (curves generated from prediction equations).

The initial moisture content of the seed had a significant effect on the final seed-mass temperature. Seed having an initial moisture content of 16% yielded the highest average temperature; however, the maximum increase in temperature was recorded for seed having an initial moisture content of 10%. For seed moisture levels of 10%, 16%, and 22% the average maximum increases in seed-mass temperature were 117.9°, 108.2°, and 91.1° F, respectively.[7]

The seed-mass temperature was also dependent upon the rate of energy application. Energy input rates of 200, 400, and 600 watts produced average seed-mass temperatures of 125.7°, 152.7°, and 180.3° F, respectively.

The time of exposure to the microwave energy had a significant effect on the seed-mass temper-

[7] The initial seed-mass temperature was 75° F.

TABLE 3.—*Treatment means of reflected energy, in watts*

Initial % seed moisture (A)	Energy input rate, watts (B)	Exposure time in minutes (C)				
		2	4	6	8	10
10	200	50.0	50.0	50.0	56.7	53.3
10	400	110.0	115.0	106.7	120.0	121.7
10	600	141.7	161.7	168.3	156.7	171.7
16	200	30.0	35.0	33.3	26.7	36.7
16	400	40.0	50.0	60.0	76.7	83.3
16	600	96.7	83.3	111.7	140.0	180.0
22	200	21.7	20.0	31.7	20.0	23.3
22	400	50.0	46.7	46.7	56.7	63.3
22	600	80.0	66.7	83.3	105.0	146.6

TABLE 4.—*Treatment means of seed-mass temperature, in °F*

Initial % seed moisture (A)	Energy input rate, watts (B)	Exposure time in minutes (C)					
		0	2	4	6	8	10
10	200	75.0	95.3	114.0	128.0	140.7	134.0
10	400	75.0	110.0	132.0	172.3	160.0	195.3
10	600	75.0	116.3	140.7	181.0	215.3	249.3
16	200	75.0	103.3	116.0	142.0	142.0	164.7
16	400	75.0	112.0	139.0	166.0	161.3	177.0
16	600	75.0	142.0	168.0	191.7	229.3	208.0
22	200	75.0	99.0	114.7	132.0	126.7	133.7
22	400	75.0	117.3	158.0	151.3	168.0	171.3
22	600	75.0	126.7	171.0	179.3	193.0	193.3

ature, which increased from an average low of 113.5° to an average high of 180.7° F as time of exposure increased from 2 to 10 minutes.

It is postulated that the irregularity in the mean seed-mass temperatures (table 4) at the exposure times greater than 6 minutes is due to either variations in moisture content throughout the seed mass or because of hot spots caused by an uneven distribution of the microwave energy by the stirrer.

A regression analysis of final seed-mass temperature with respect to exposure time yielded predicting equations for the various combinations of seed moisture level and energy input rate. The coefficients of determination of these equations ranged from a low of 0.81 to a high of 0.96. The curves are plotted in figures 8, 9, and 10.

Energy Utilization

An analysis of the data at each seed moisture level indicated the amount of moisture removed by a specified quantity of effective energy was virtually constant for all energy input rates. For seed moisture levels of 10%, 16%, and 22%, the amount of moisture removed per kilowatt-minute of effective energy averaged 6.2, 8.5, and 9.2 grams, respectively. The higher energy input rates only increased the rate of moisture removal. The efficiency of removal at specified seed moisture levels remained virtually unchanged (table 5).

The utilization of the energy supplied to the microwave cavity can be viewed in several ways. The effective energy was determined to be the product of the rate of energy absorption (watts)

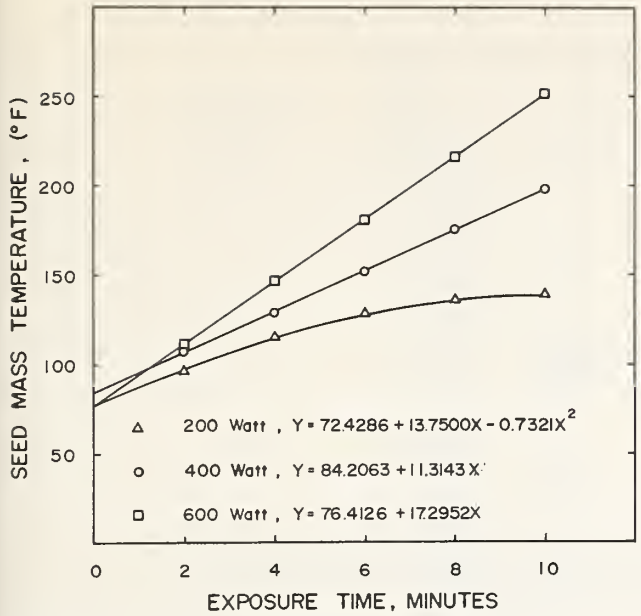

FIGURE 8.—Seed-mass temperature versus exposure time for seed having an initial moisture content of 10% (curves generated from prediction equations).

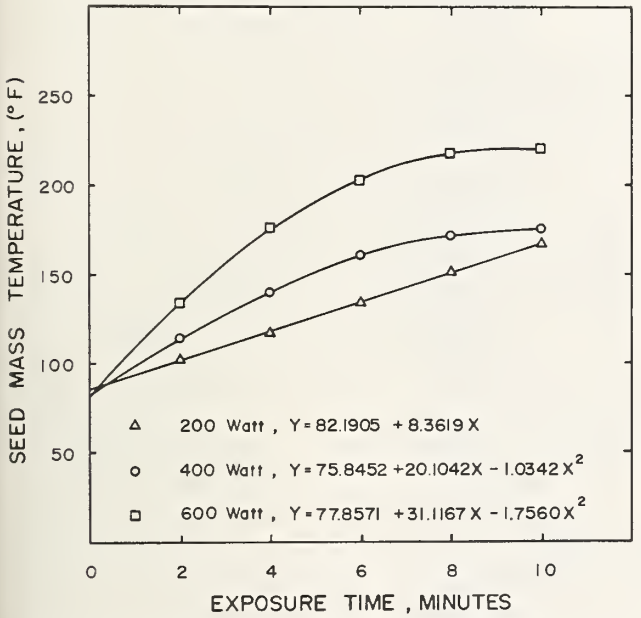

FIGURE 9.—Seed-mass temperature versus exposure time for seed having an initial moisture content of 16% (curves generated from prediction equations).

and the exposure time (minutes). The percentage of transmitted energy converted to effective energy was dependent on the initial seed moisture level and progressively increased as the initial seed moisture level increased. The percentage of effective energy at seed moisture levels of 10%, 16%, and 22% averaged 73.2, 82.6, and 86.4, respectively. Previous research

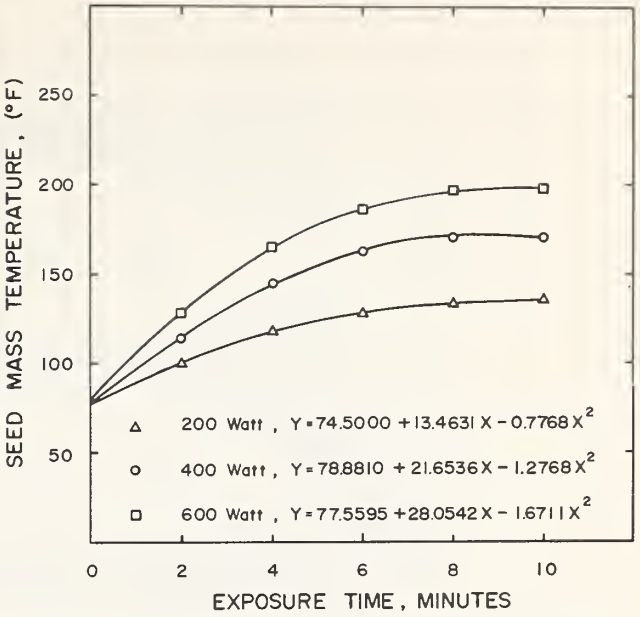

FIGURE 10.—Seed-mass temperature versus exposure time for seed having an initial moisture content of 22% (curves generated from prediction equations).

(*4*) suggests that the utilization rate of the transmitted energy is also dependent on the selected sample size. Increased sample size tended to increase the rate of utilization.

The portion of the transmitted energy used to remove moisture from the cottonseed varied from a low of 17.3% to a high of 31.4%.[8] The energy required to remove moisture from the seed ranged from 23.6% to 36.1% of the effective energy level and was dependent on the initial seed moisture level. These data are summarized in table 5.

Seed Germination

The analysis of variance indicated that all main factors, and interactions AC and BC, were significant at the 0.01 probability level. Means of the seed germination data are recorded in table 6.

Seed germination tended to decrease with increasing moisture level, energy input rate, and exposure time.

Individual germination data indicate an enhancement of seed germination when the seed was exposed to 200 watts for 2 minutes. This favorable response warrants additional investi-

[8] The energy required to remove the moisture from the cottonseed is the product of the moisture removed in pounds (table 2) and the latent heat of vaporization at the given seed-mass temperature.

TABLE 5.—*Utilization of microwave energy for drying cottonseed at various seed moisture levels and energy input rates*

Initial % seed moisture	Energy input rate, watts	Mean seed-mass temperature, ° F	Moisture removed,[1] grams	Utilization of microwave energy					
				Transmitted energy,[2] Btu	Effective energy,[3] Btu	Ratio of effective energy to transmitted energy, %	Energy required for moisture removal,[4] Btu	Ratio of energy required for moisture removal to transmitted energy, %	Ratio of energy required for moisture removal to effective energy, %
10	200	122	9.23	113.8	84.2	74.0	20.9	18.4	24.8
10	400	154	18.00	227.6	164.7	72.4	40.7	17.9	24.7
10	600	180	26.30	341.4	250.4	73.3	59.0	17.3	23.6
16	200	134	14.90	113.8	95.4	83.8	33.1	29.1	34.7
16	400	151	27.30	227.6	192.4	84.5	60.6	26.6	31.5
16	600	188	41.03	341.4	271.9	79.6	91.6	26.8	33.7
22	200	121	15.73	113.8	100.6	88.4	34.5	30.3	34.3
22	400	153	32.70	227.6	197.7	86.9	71.4	31.4	36.1
22	600	173	46.53	341.4	286.7	84.0	101.2	29.6	35.3

[1] Moisture removed from 700 grams of cottonseed after 10 minutes of exposure to the microwave energy.

[2] Transmitted energy is the product of energy input rate (watts) and exposure time (10 minutes). Units are converted to British thermal units.

[3] Effective energy is the product of the rate of energy absorption (watts) and the exposure time (minutes) converted to British thermal units.

[4] Energy required for moisture removal is the product of moisture removed in pounds and the latent heat of vaporization at the respective seed-mass temperature.

TABLE 6.—*Means of seed germination, in percent*[1]

Initial % seed moisture (A)	Energy input rate, watts (B)	Exposure time in minutes (C)				
		2	4	6	8	10
10	200	76.7	76.0	65.8	60.7	54.8
10	400	76.7	58.5	45.0	28.7	20.8
10	600	69.3	44.2	19.2	7.5	7.0
16	200	63.3	60.7	53.0	47.5	34.3
16	400	53.2	40.0	17.2	13.8	8.8
16	600	45.8	24.5	4.3	3.0	1.3
22	200	61.0	55.5	54.2	53.8	44.7
22	400	56.7	37.0	23.0	16.2	11.3
22	600	52.8	19.0	4.0	1.3	.8

[1] The seed germination tests made on the control samples from 10%, 16%, and 22% seed moisture levels averaged 72.0%, 53.8%, and 54.3%, respectively.

gation to determine the relationship and optimum levels of cottonseed moisture, energy input rate, and time of exposure to produce maximum increases in seed germination.

Three germination tests were made on the control samples of each seed moisture level. Results of these germination tests for the 10%, 16%, and 22% moisture level averaged 72.0%, 53.8%, and 54.3%, respectively. After subjecting the seed to 200 watts energy for 2 minutes, the germination of the seed at the 10%, 16%, and 22% moisture level increased to 76.7%, 63.3%, and 61.0%, respectively. These increases were obtained at an average effective energy level of approximately 2.84 watt-seconds per seed.[9]

Regression analysis of seed germination for the various combinations of seed moisture and energy input rates indicated that a third-degree polynomial best described the data for seven of the nine treatment combinations. The exceptions were the combination of 16% seed moisture and 200-watt energy input and the 22% moisture and 200-watt energy. The combination of 16% seed moisture and 200-watt energy input was determined to be quadratic, whereas the scatter of the data for the 22% seed moisture and 200-watt energy level was such that a linear relationship failed to be significant. The coefficients of determination for the eight significant polynomials ranged from 0.61 to 0.97. The curves for the combinations are shown in figures 11, 12, and 13.

[9] The quotient obtained from effective energy divided by the total number of seeds in the sample. The number of seeds per sample = sample weight (grams) × 10 seeds/gram.

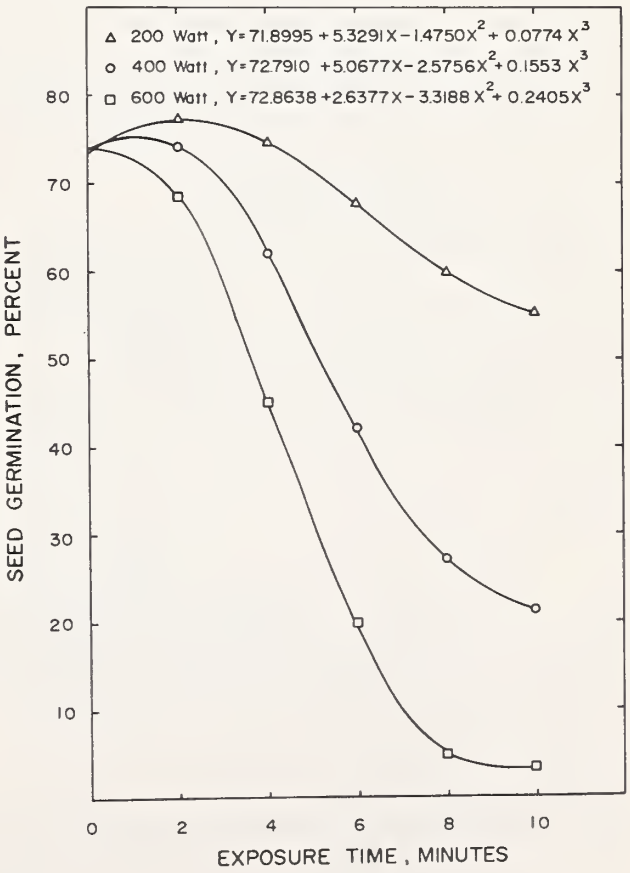

FIGURE 11.—Seed germination versus exposure time for seed having an initial moisture content of 10% (curves generated from prediction equations).

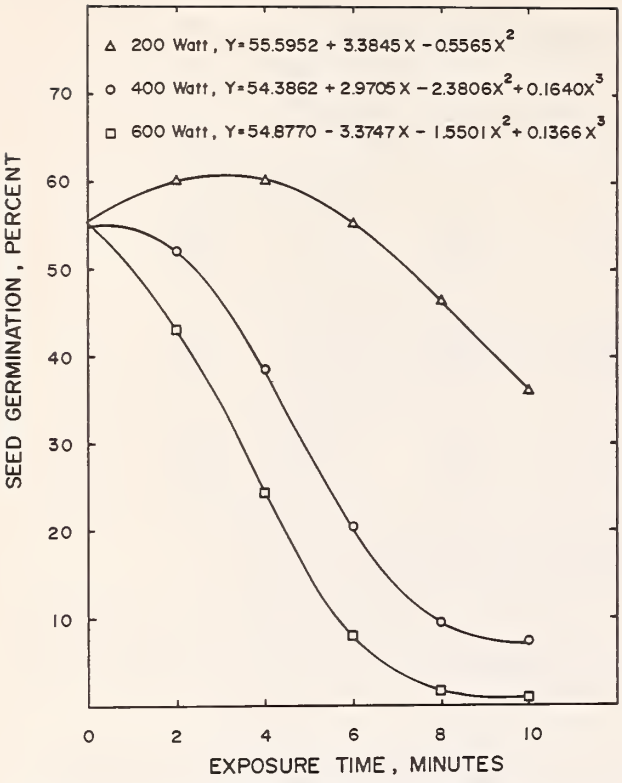

FIGURE 12.—Seed germination versus exposure time for seed having an initial moisture content of 16% (curves generated from prediction equations).

CONCLUSIONS

The investigation of microwave drying of cottonseed gave insight into the practicality of using microwave energy for drying seed cotton. The following information was developed:

1. Drying curves were developed with respect to exposure time for the combinations of seed moisture and energy input rates. Maximum reduction in seed moisture was recorded for the treatment combination of 22% seed moisture and 600-watt energy input.

2. Equations were developed to predict seed-mass temperature as a function of exposure time. The temperature of the seed mass was determined to be dependent on the initial moisture content, energy input rate, and time of exposure of the seed to the microwave energy. Maximum increases in seed-mass temperature were recorded for the 10% seed moisture level, 600-watt energy input rate, and 10-minute exposure time.

3. For each moisture level, the amount of moisture removed by a given quantity of effective energy was virtually constant for all energy input rates. For seed moisture levels of 10%, 16%, and 22%, the amount of moisture removed per kilowatt-minute averaged 6.2, 8.5, and 9.2 grams, respectively.

4. The utilization of transmitted energy for removing moisture from the seed ranged from 17.3% to 31.4% and was dependent on the initial seed moisture level. The portion of the effective energy used for removing moisture ranged from 23.6% to 36.1%. The remaining percentage of the energy was either reflected to the magnetron because of the small sample size and moisture level, or went to raise the temperature of the cottonseed, moisture within the seed, and the surroundings.

5. Seed germination curves were developed with respect to exposure time. Data for certain treatment combinations indicated a significant cubic factor; however, for practical applications, the response curve must be limited to a quadratic response. Data revealed a significant increase in germination of seed exposed to 200 watts of energy for 2 and 4 minutes. Increases were also recorded for seed exposed to the 400-watt energy

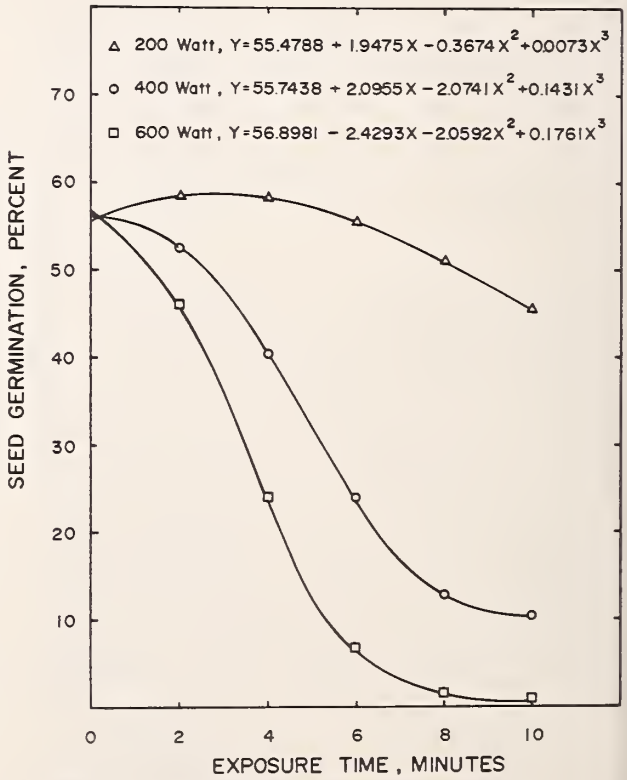

FIGURE 13.—Seed germination versus exposure time for seed having an initial moisture content of 22% (curves generated from prediction equations).

level for 2 minutes. Extended exposure times at all energy levels significantly decreased seed germination. In this investigation, cottonseed viability was increased when seed was exposed to effective energy levels between 0.300 and 0.750 kilowatt-minutes per 700-gram sample. Beyond 0.750 kilowatt-minutes, seed viability decreased.

Additional research is needed to determine the effects of microwave energy on seed cotton. The absorptive characteristics or loss factor of both cottonseed and lint must be determined before valid conclusions can be made concerning the practicality of microwave drying for improving seed cotton processing at cotton gins.

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